Application For

Design-Based Fuel Pathway for Ethanol Production with CCS

CARB-1, Plainview and Hereford TX

Oxy Carbon Storage, LLC & White Energy, Inc.

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1. Project Overview

This is a Design-based pathway application for ethanol production with carbon capture and sequestration (Ethanol + CCS). Oxy Carbon Storage, LLC (Oxy) and White Energy, Inc. (WE) have partnered to build and install CO2 capture equipment at two of White Energy's ethanol plants located in Plainview, TX (PWE) and Hereford, TX (HWE). This document constitutes the LCA (Life Cycle Analysis) report described in 95488.7(a)(2).

WE's PWE plant has four CARB certified ethanol fuel pathways and WE's HWE plant has two CARB certified pathways. Table 1 summarizes the relevant certified ethanol pathways held by WE for this Design-based pathway application, see Appendix 7.1 for additional pathway details.

Table 1 WE's Ethanol Fuel Pathways

CA GREET 3.0 FPC	Plant	Feedstock	CI Value (gCO2e/MJ)
ETH009A01610400	PWE	Corn, Dry	72.64
ETH009A01610100	PWE	Corn, Wet	64.69
ETH010A01610500	PWE	Sorghum, Dry	74.57
ETH010A01610300	PWE	Sorghum, Wet	66.62
ETH009A01630100	HWE	Corn	64.74
ETH010A01630200	HWE	Sorghum	66.63

Approximately 20 MMSCF per day of biogenic CO2 generated during the ethanol production process will be captured at each WE plant, dehydrated, compressed, metered into the Permian CO2 Pipeline Network (at two separate locations, one near Plainview and one near Hereford) and metered out at CARB-1, Oxy's storage facility located in Gaines County, TX. CARB-1 is a project to sequester biogenic CO2 using CO2-EOR at the West Seminole San Andres Unit ("WSSAU") project in accordance with the Carbon Capture and Sequestration Protocol ("CCS Protocol") under the Low Carbon Fuel Standard ("LCFS"). A Permanence Certification application (Application No. D001001) for CARB-1 was submitted to CARB on November 4, 2019 and is pending review and approval. The sequestered biogenic CO2 from WE's ethanol production process will reduce the CI for each ethanol fuel pathway by 25.56 gCO2/MJ. The Ethanol + CCS pathway described in this application is identical for all six CARB certified ethanol pathways held by WE, including the CI reduction, calculator inputs and verification methods. However, the original CI values for each pathway vary and, consequently, the CI for each Design-based pathway, as calculated with the CI reduction attributable to CCS, will vary.

2. System Boundary

Pursuant to CCSP B.1, Figure 1, the quantification in this application includes all CO2 sources, sinks, and reservoirs (SSRs) from the CARB-1 Project.

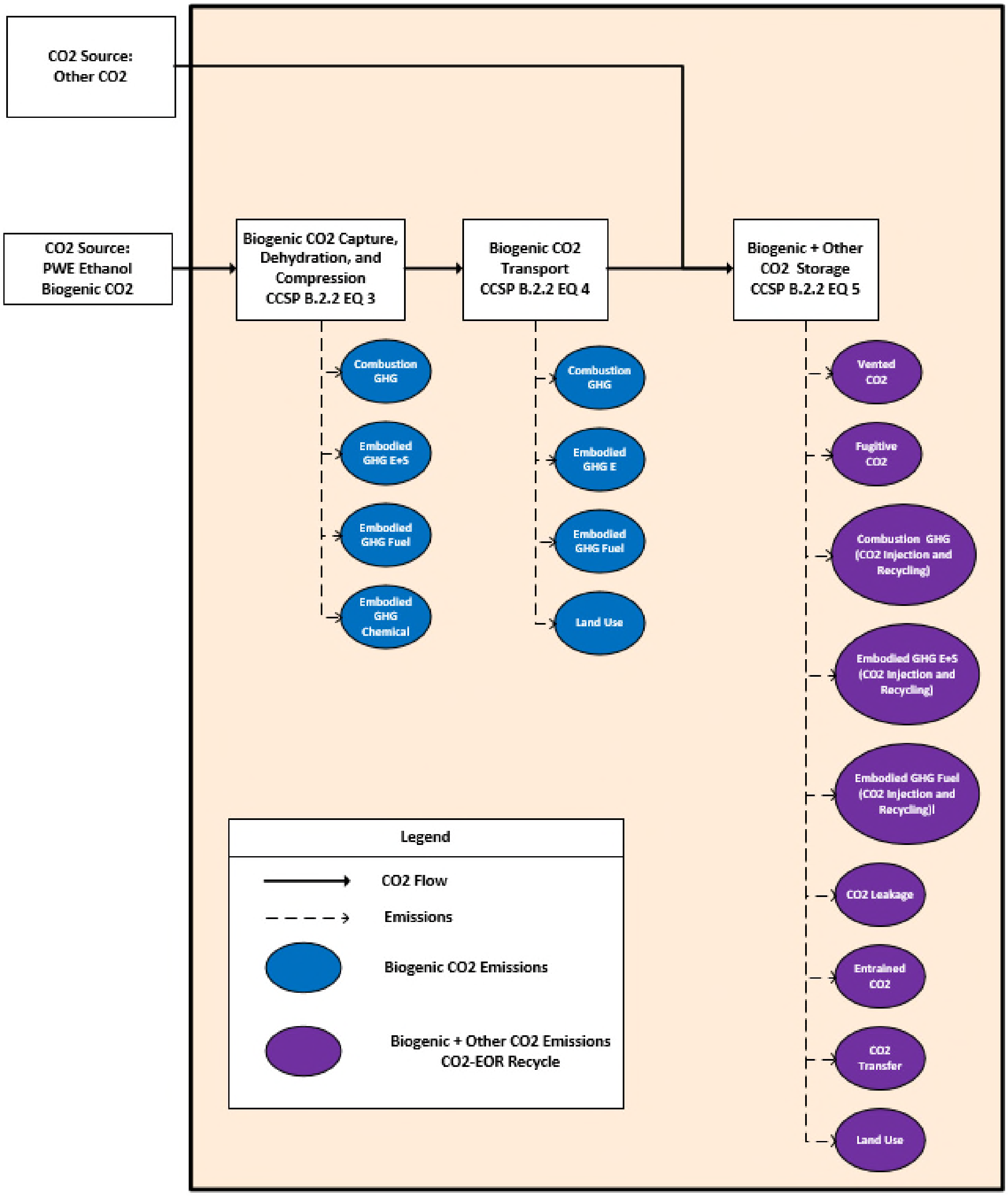

Figure 1 – System Boundary Diagram for Ethanol + CCS Project

3. Quantification Methodology

This application includes a Tier 1 ethanol calculator for starch and fiber ethanol (August 13, 2018 release) that has been modified to include the equations necessary to quantify net annual GHG emission reductions from the CCS project and to factor those reductions into revised CI values for each of WE's relevant fuel pathways. The modified Tier 1 ethanol calculator for the Ethanol + CCS Project (the CARB-1 CI calculator) has been uploaded to the AFP (Alternative Fuels Portal).

The full list of equations used in estimating the ethanol CI reduction can be seen in Appendix 7.3 and in the CARB-1 CI calculator; they include the equations in the CCSP B.2.2(a)-(e) and the additional allocation equation in the following order:

1. B.2.2(c) GHG emissions from carbon capture, dehydration, and compression from the ethanol plant are quantified using Equation 3 (EQ3).
2. B.2.2(d) GHG emissions from CO2 transport are quantified using Equation 4 (EQ4).
3. B.2.2(e) GHG emissions from CO2 injection operations are quantified using Equation 5 (EQ5) and are then allocated to biogenic CO2 using a CO2 Allocation Factor (CAF).
4. B.2.2(b) CCS project GHG emissions associated with the injection of biogenic CO2 from ethanol production are quantified using Equation 2 (EQ2).
5. B.2.2(a) Net GHG emissions reduction are determined for ethanol plants using Equation 1 (EQ1).
6. LCFS 95490(b)(6), the amount of net CO2 sequestered by alternative fuel producers can be used to adjust the carbon intensities of the associated fuel pathways. Net GHG emissions reduction determined using EQ1 is equally distributed to all associated fuel pathways used to produce ethanol during the production period.

Estimated operating data for the CARB-1 CI calculator has been populated for Q4 2021 in alignment with the current CARB-1 Project schedule. The key inputs for the CARB-1 CI calculator are in Table 2 below. These inputs are the critical verification parameters as identified by Oxy to maintain compliance with the monitoring requirements of the CCSP.

The indirect land use change (ILUC) associated with this project is omitted in accordance with CCSP B. 2.2 (f). The direct land use change (DLUC) associated with this project is quantified in Equation 2 from CCSP B.2.2(b). The land use change for WE's Plainview ethanol plant will remain unchanged by the CCS portion of this project.

Table 2 CARB-1 CI Calculator Inputs and Verification Methods

CCS Project Phase	CO2 Source and Tracked Emissions	Emission Source	Net GHG Variable	Related Variables and EQ	Verification
CO2 Capture and Processing	Captured biogenic CO2 from Ethanol Production	NA	EQ1 - Amount Injected	EQ4 to allocate portion of total power to captured volume CAF to determine ratio of biogenic to other CO2 in CARB-1	Calibrated flow meters and monthly sales transactions.
	Inlet Blower Compression Dehydration [redacted]	Grid Power Other Gas	EQ3 - Embodied GHG_{Elect} Embodied GHG_{fuel}	EQ3 results used in EQ2	Power for CO2 capture and processing system will be on an invoice, tracked monthly. Natural gas use will be determined from calibrated flow meters. Make up [redacted] and chemical invoices as needed by capture process.
	[redacted]	Power, de minimis [redacted] make-up	EQ3 - Embodied GHG_{Elect} Embodied GHG_{Chem}	EQ3 results used in EQ2	
	Utilities & Chemicals	Power, de minimis chemical make up	EQ3 - Embodied GHG_{Elect} Embodied GHG_{Chem}	EQ3 results used in EQ2	
CO2 Transport	CO2 Transfer Pumps	Grid Power Other Gas	EQ4- Embodied GHG_{Elect} Embodied GHG_{fuel}	EQ4 results used in EQ2	Power for CO2 transport pump will be on an invoice, tracked monthly. Natural gas use will be determined from calibrated flow meters.
CO2 Injection Operations	Purchased CO2 Volume	NA	NA	Compared to total captured biogenic CO2 to confirm injection volume for EQ1 Summed over time to quantify total inventory and determine ratio of biogenic to other CO2 in CARB-1 for CO2 Allocation Factor	Book and claim accounting. Calibrated CO2 pipeline flow meters, monthly CO2 data, CARB-1 CO2 inventory.

CO2 Injection Operations	Dehydration	Grid Power Other Gas	EQ5 - Embodied GHG$_{Elect}$ EQ5 - Embodied GHG$_{fuel}$	EQ5 results adjusted using CO2 Allocation Factor EQ5 results used in EQ2	Power for recycle compression and auxiliary systems will be on an invoice, tracked monthly. Natural gas use will be determined from calibrated flow meters.
	Recycle Compression	Grid Power	EQ5 - Embodied GHG$_{Elect}$		
	CO2-EOR Injection Emissions	Pipe, valves, fitting, and equipment counts	EQ5 - Vented CO2 EQ5 - Fugitive CO2	EQ5 results adjusted using CO2 Allocation Factor EQ5 results used in EQ2	Mandatory Reporting Rule (MRR) for GHG
	CO2-EOR Reservoir Leakage	Wellbore Leakage	EQ5 - CO2 Leakage		WSSAU Reservoir Leakage Model and field monitoring program under CCS Protocol. See WSSAU Permanence Certification application for more detail.
	Entrained CO2 in Oil Sales Volume	CO2 Solubility in Crude Oil Sales	EQ5 - CO2 Entrained		LACT (Lease Automated Custody Transfer) Oil Sales Tickets/Receipts Crude Oil Composition Analysis by Third Party Analytical Lab
	Lease to Lease CO2 Transfer	Transfer Outside System Boundary	EQ5 - CO2 Transfer		CARB-1 Calibrated Field Flow Meter Data

4. Ethanol + CCS Fuel Pathway Carbon Intensity (CI) Calculation - Summary Results

Assuming 20 MMSCF per day per ethanol plant (total biogenic CO2 volume of approximately 40 MMSCF per day for both capture plants) and the estimated operating data in the CARB-1 CI calculator, Table 3 presents tabulated results from the CARB-1 CI calculator for the Ethanol + CCS Project CI reduction.

Table 3 CI Reduction and Net GHG Emissions Calculation Details

Section 12. CI Reduction and Net GHG Calculation Details		
Category	**Parameters**	**CI Calculations**
		CI
GHG Emissions Reduction **B.2.2 (a) EQ1**	**GHGreduction**	**25.56** *gCO2e/MJ*
	GHGproject	**7.27** *gCO2e/MJ*
	CO2injected	**32.83** *gCO2e/MJ*

The results in Table 3 show a CI reduction of 25.56 gCO2e/MJ. As described earlier, while the Ethanol + CCS pathway described in this application is identical for all six CARB certified ethanol pathways held by WE, the original CI values for each pathway vary and, consequently, the CI for each Design-based pathway, as calculated with the CI reduction attributable to CCS, will vary. Table 4 shows the resulting adjusted CI values for each WE fuel pathway.

Table 4 Adjusted Ethanol Fuel Pathway CI Estimates

CA GREET 3.0 FPC	Plant	Feedstock	Certified CI (gCO2e/MJ)	CI Reduction (gCO2e/MJ)	Adjusted CI (gCO2e/MJ)
ETH009A01610400	PWE	Corn, Dry	72.64	25.56	47.08
ETH009A01610100	PWE	Corn, Wet	64.69	25.56	39.13
ETH010A01610500	PWE	Sorghum, Dry	74.57	25.56	49.01
ETH010A01610300	PWE	Sorghum, Wet	66.62	25.56	41.06
ETH009A01630100	HWE	Corn	64.74	25.56	39.18
ETH010A01630200	HWE	Sorghum	66.63	25.56	41.07

5. Ethanol + CCS Fuel Pathway Carbon Intensity (CI) Calculation - Details

This section summarizes key assumptions for the results listed in Table 3 and where the underlying calculations are performed in the CARB-1 CI calculator. CCS Project emissions inputs are based on design values. The data is presented as a provisional pathway example using the CARB-1 CI calculator for ease of reference and familiarity to the CARB review team.

5.1. CCSP B.2.2(c) EQ3 Capture System GHG Emissions

5.1.1. CO2 Volume Assumption

WE's PWE and HWE plants will each generate approximately 20 MMSCF of biogenic CO2 per day, for a total of 40 MMSCF per day. This application assumes a stoichiometric balance of CO2 from ethanol production and 95% recovery from the CO2 Capture facilities. The calculations necessary to balance the ethanol with the captured CO2 are provided in the CARB-1 CI calculator under the CO2 Basis sheet.

5.1.2. CO2 Capture Emissions Inputs

No specialty chemicals are used for CO2 Capture as defined in the CCSP B.2.2(c)[1]. Instead, [redacted] combined with [redacted] is used to purify the CO2. Thus, there are six emission inputs for Equation 3:

i. Energy associated with the inlet gas blower
ii. Energy associated with compression
iii. Energy associated with dehydration
iv. Energy associated with [redacted]
v. Energy associated with [redacted]
vi. Energy associated with instrumentation air

The energy requirements for inputs 5.1.2. i-vi were determined via process simulation modeling with Aspen HYSYS. A process flow diagram (PFD) illustrating the capture process has been uploaded to the AFP. The CO2 capture process is shown by drawings PER-TBD-PRO-00001-001 through PER-TBD-PRO-00001-004. The model results are consistent with available literature data on CO2 processing. The simulated energy demand for the proposed CARB-1 CO2 Capture Facility is [redacted] per tonne of CO2. This value is consistent with a study from UC Davis[2] and CA_GREET 3.0[3].

The modeled monthly electricity use is multiplied by the regional eGRID emissions factor (9-SPSO mix for PWE) to determine embodied CO2e for electricity.

Table 5 presents a summary of the emission inputs and the total embodied CO2e for each step in the Capture Process. The input details for these equations are in the CARB-1 CI Calculator, CCS Energy sheet. The calculations in Table 5 assume 92 days in Q4 2021. The estimated facility operating load for Q4 2021 is included in the inputs for the CARB-1 CI calculator in the CO2-EOR sheet, Section 7.7 Electricity Use from grid.

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[1] The embedded GHG emissions for the [redacted], [redacted], and compressor lube oils are negligible compared to the embedded GHG emissions for grid electricity use (< 10 MT CO2e/year). These emissions are considered de minimis and are not included in the CI calculation. The estimated chemical use and associated emissions can be found in Appendix Section 7.5.2.

[2] McCollum, D. L., & Ogden, J. M. (2006). Techno-economic models for carbon dioxide compression, transport, and storage & correlations for estimating carbon dioxide density and viscosity.

[3] CA_GREET 3.0 calculates the compression energy for pure CO2 to be 100 kWh per tonne of CO2 from atmospheric pressure to 2,175 psia on the Compression Sheet. The proposed analysis should be greater as it includes [redacted] energy to [redacted] the CO2 and compression to a higher outlet pressure.

Table 5 Capture Process Emissions Inputs

Plant	Process Stage	Simulated Energy Demand (kW)	Estimated Operating Load Q4 2021 (kWh/Month)	Estimated GHG Emissions Q4 2021 (MT CO2e/Month)	Estimated GHG Annual Emissions (MT CO2e/Year)
PWE	Inlet CO2 Blower	[redacted]	[redacted]	[redacted]	[redacted]
PWE	CO2 Compression and Dehydration	[redacted]	[redacted]	[redacted]	[redacted]
PWE	CO2 [redacted] and [redacted]	[redacted]	[redacted]	[redacted]	[redacted]
PWE	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
PWE	Utilities	75	54,884	44	519
PWE	Chemicals	0	0	0	0
TOTAL		[redacted]	[redacted]	[redacted]	[redacted]

5.2. CCSP B.2.2(d) EQ 4 Transportation System GHG Emissions

5.2.1. CO2 Volume Assumption

The biogenic CO2 from each WE plant will be transported to CARB-1 through the Permian CO2 Pipeline Network. The biogenic CO2 will be metered prior to entering the network and metered out at CARB-1. For the CO2 Transport GHG emissions calculation, the assumed CO2 volume from each plant is 20 MMSCF per day.

5.2.2. CO2 Transport Emissions Inputs

The process consists of supercritical phase CO2 transfer pumps that compress the CO2 to pipeline pressure and then to CARB-1. As a result, there is one emission input for Equation 4:

i. Energy associated with CO2 transfer pumps

The estimated transport distance for the captured biogenic CO2 is 139 miles for PWE and 183 miles for HWE from the point of capture to the point of sequestration in CARB-1. A hydraulic analysis was performed using PIPESIM (Schlumberger's steady-state multiphase flow simulator) to calculate the energy required to transport the biogenic CO2 to CARB-1. Hydraulic simulation results are in Appendix 7.4.2.

A pipeline diagram illustrating the CO2 transportation route and calculated hydraulic profile is also available in the accompanying PFD drawing PER-TBD-PRO-00001-005.

Table 6 presents a summary of the transportation system emission inputs and the total embodied CO2e. The calculations in Table 6 assume 92 days Q4 2021. The estimated operating load for Q4 2021 is also included in the inputs for CARB-1 CI calculator in the CO2-EOR sheet, Section 7.7 Electricity Use from Grid.

Table 6 Transport Process Emissions Inputs

Plant	Process Stage	Simulated Energy Demand (kW)	Estimated Operating Load Q4 2021 (kWh/Month)	Estimated GHG Emissions Q4 2021 (MT CO2e/Month)	Estimated GHG Annual Emissions (MT CO2e/Year)
PWE	CO2 Transfer Pumps	[redacted]	[redacted]	[redacted]	[redacted]

5.3. CCSP B.2.2(e) EQ 5 CO2 Injection Operations GHG Emissions

5.3.1. CO2 Volume Assumption

Dedicated and calibrated flowmeters will be installed to meter and account for the biogenic CO2 captured at each WE plant and delivered to the Permian CO2 Pipeline Network. Existing dedicated and calibrated flowmeters will properly meter and account for the biogenic CO2 delivered to CARB-1. Flow meter data will be used to confirm receipt of approximately 20 MMSCF per day from each ethanol plant, for an assumed total of 40 MMSCF per day. CARB-1 may also receive CO2 from other sources and the total CO2 injected at CARB-1 may exceed 40 MMSCF per day. However, this Design-based pathway calculates CI reduction based solely on the biogenic CO2 received from WE. CO2 from other sources will be allocated to other pathways. As required by the CCS Protocol (1) All metered measurements of inputs to GHG emissions reductions; (2) Analysis of the CO2 stream; and, (3) Injection rate and volume will be reported on a quarterly or annual basis.

5.3.2. CO2 Allocation Methodology

Emissions associated with CO2 injection and recycling are allocated to the biogenic CO2 from each ethanol plant using a CO2 Allocation Factor (CAF). The CAF is the ratio of biogenic CO2 from the selected WE ethanol plant to the total CO2 sequestered: $CAF = (\text{Biogenic } CO2_{injected}) / (\text{Total } CO2_{Sequestered})$. The calculation for the CAF is provided in the CARB-1 CI calculator.

Only the energy inputs and emissions attributable to the biogenic CO2 from the WE ethanol plants will be allocated to the ethanol fuel pathways. Other energy inputs and emissions attributable to the sequestered CO2 which do not generate LCFS credits are allocated to CO2-EOR crude oil and gas production.

The CAF is calculated using a mass balance approach in accordance with the CCSP B.2.2(a). The Design-based pathway initially calculates the CAF to be [redacted]% for a single WE ethanol plant.

5.3.2.1. Determining Net GHG Emissions from CCS Project Injection Operations

The injection operation is primarily electrically driven with some onsite combustion. Natural gas is used in the dehydration process. As a result, there are seven emission inputs for Equation 5:

i. Energy from natural gas combustion associated with CO2 dehydration at the RCF (Recompression Facility)
ii. Energy associated with CO2 recompression at the RCF
iii. Emissions from Vented CO2
iv. Emissions from Fugitive CO2
v. Emissions from Entrained CO2

vi. Emissions from CO2 Leakage
vii. Emissions from CO2 Transfer

A block flow diagram of the CO2 Injection site is available in the accompanying PFD drawing PER-TBD-PRO-00001-006. The PFD includes estimated data for the project year 2021.

Table 7 presents a summary of the CO2 injection system emission inputs and the total embodied CO2e for each input before allocation.

The other gas and electricity demand for 2021 have been estimated assuming full RCF nameplate capacity that has been scaled to handle the increasing recycle CO2-EOR injection volumes anticipated in Q4 2021. Estimated natural gas and electricity demand has been included in the CARB-1 CI calculator in the CCS Energy sheet.

The CO2 Venting and Fugitive emissions have been calculated according to CCSP Appendix B. CO2 Venting and Fugitive Emissions from CO2-EOR Operations in accordance with CCSP B.2.2(e). The MRR calculation summary for these estimates can be found in Appendix 7.5.1.

The CO2 Entrained emissions considered in this application have been limited to the CO2 entrained in crude oil sales. The entrained CO2 emissions for produced gas and water are omitted from the CO2 Entrained emissions as they are reinjected and therefore exempt from accounting per section CCSP B.2.2.(e) definition of $CO2_{entrained}$. See Appendix 7.5.3 for CO2 Entrained calculations.

Table 7 Injection Operations Emission Inputs

Process Stage & Emissions Inputs	Forecasted Energy Demand (kW)	Estimated Operating Load Q4 2021 (kWh/Month)	Forecasted Fuel Consumption Q4 2021 (mmBTU/Month)	Estimated GHG Emissions Q4 2021 (MT CO2e/Month)	Estimated GHG Annual Emissions (MT CO2e/Year)
CO2 RCF Fuel Gas	0	0	[redacted]	[redacted]	[redacted]
CO2 RCF Electricity	[redacted]	[redacted]	0	[redacted]	[redacted]
CO2 Venting	0	0	0	94.45	1,124
CO2 Fugitives	0	0	0	16.87	201
CO2 Entrained in Oil	0	0	0	14	162
CO2 Leakage from Reservoir	0	0	0	0	0
CO2 Transfer	0	0	0	0	0
Total	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

5.3.2.2. Allocating Net GHG Emissions to Ethanol Production

Net GHG emissions from CO2 Injection operations are allocated to the biogenic CO2 captured from PWE ethanol plant using CAF as indicated in Table 8 and Table 9 below. Other Biogenic CO2 Emissions represent the emissions allocated to the biogenic CO2 captured from the HWE ethanol plant.

The allocation tables have been set up to mimic those in the simplified Tier-1 ethanol CI calculator. As such, they are placed beneath the operating data that is being allocated in the CARB-1 CI calculator.

Table 8 Net GHG Emissions from Energy Allocated to Ethanol Production

Allocation Calculations: Section 7. Energy Consumption for Biogenic CO2 Capture and Transport							
Allocated Natural Gas Emissions				Allocated Electricity Emissions			
Biogenic CO2 Emissions	0	MT CO2e		Biogenic CO2 Emissions	[redacted]	MT CO2e	
Other CO2 Emissions	0			Other CO2 Emissions	0		
Other Biogenic CO2 Emissions	0			Other Biogenic CO2 Emissions	0		
Emissions Check	Good		0	Emissions Check	Good		0

Table 9 Net GHG Emissions from Injection Operations Allocated to Ethanol Production

Allocation Calculations: Section 10 Energy Consumption for CO2 Injection and CO2-EOR Recycle							
Allocated Natural Gas Emissions				Allocated Electricity Emissions			
CAF, 2021	[redacted]			CAF, 2021	[redacted]		
Recycle CO2%, 2021				Recycle CO2%, 2021			
Biogenic CO2 Emissions		MT CO2e		Biogenic CO2 Emissions		MT CO2e	
Other CO2 Emissions				Other CO2 Emissions			
Other Biogenic CO2 Emissions				Other Biogenic CO2 Emissions			
CO2-EOR Gas Processing				CO2-EOR Gas Processing			
Emissions Check	Good		0	Emissions Check	Good		0

5.4. CCSP B.2.2(b) Net GHG Emissions from CCS Project

Equation 2 from the CCSP B.2.2(b) is used to calculate net GHG emissions from the CCS project as indicated in Table 10 and using the data from Tables 5, 6, 8, and 9 above.

Table 10 Net GHG Emissions from the CARB-1 Project

Section 12. CI Reduction and Net GHG Calculation Details					
Category	Parameters	CI Calculations			
		Input Data	Total	Biogenic, Single EtOH	CI
GHG Project Emissions B.2.2 (b) EQ2	GHGproject		35,741.25 *Metric Tonnes CO2e*	21,552.20 *Metric Tonnes CO2e*	7.27 *gCO2e/MJ*
	GHGcapture+ GHGtransport		[redacted] *Metric Tonnes CO2e*	[redacted] *Metric Tonnes CO2e*	[redacted] *gCO2e/MJ*
	GHGinjection		[redacted] *Metric Tonnes CO2e*	[redacted] *Metric Tonnes CO2e*	[redacted] *gCO2e/MJ*

5.5. CCSP B.2.2(a) Net GHG Emissions from CCS Project

Equation 1 from CCSP B.2.2(a) is used to calculate the annual GHG emissions reduction from the CCS Project as indicated in Table 11. The amount of biogenic CO2 injected is the amount captured and then tracked using book and claim accounting to injection.

Table 11 Quarterly GHG Emission Reductions from the CCS Project

Section 12. CI Reduction and Net GHG Calculation Details			
Category	Parameters	CI Calculations	
		Input Data	Biogenic, Single EtOH
GHG Emissions Reduction B.2.2 (a) EQ1	GHGreduction		75,761.92 *Metric Tonnes CO2e*
	GHGproject		21,552.20 *Metric Tonnes CO2e*
	CO2injected	97,314.11 *Metric Tonnes CO2*	

5.6. Revised Ethanol Fuel Pathway CI Calculations

The individual fuel pathway CI reductions are calculated in accordance with LCFS 95490(b)(6), the amount of net CO2 sequestered by alternative fuel producers can be used to adjust the carbon intensities of the associated fuel pathways. Net GHG emissions reduction determined using Equation 1 is equally distributed to all associated fuel pathways used to produce ethanol during the production period.

The net GHG emission reduction from the CCS Project is subtracted from the four certified PWE fuel pathways in the CARB-1 calculator and included on the EtOH Summary sheet. The tabulated ethanol fuel pathway CI reduction results are available in Table 12 below for the PWE certified fuel pathways during the assumed reporting period, Q4 2021.[4]

Table 12 Revised Ethanol Fuel Pathway CI Reduction Results

CA GREET 3.0 FPC	Plant	Feedstock	Certified CI (gCO2e/MJ)	CI Reduction (gCO2e/MJ)	Adjusted CI (gCO2e/MJ)
ETH009A01610400	PWE	Corn, Dry	72.64	25.56	47.08
ETH009A01610100	PWE	Corn, Wet	64.69	25.56	39.13
ETH010A01610500	PWE	Sorghum, Dry	74.57	25.56	49.01
ETH010A01610300	PWE	Sorghum, Wet	66.62	25.56	41.06

[4]The final ethanol fuel pathway CI scores in the calculator differ slightly from those presented in Table 12 due to the use of forecast data to represent WE Q4 2021 production.

6. References

Several sources are referenced throughout this application package. Some of these are data tables and drawings that are included in the Application Package. Others are models and external datasets for which specific page references are indicated in the application package and the general citations (and shortcut terms) are listed below:

1. CA – LCFS: California Low Carbon Fuel Standard Regulation. The official version is published as CA CCR Title 17, Division 3, Chapter 1, Subchapter 10, Article 7 (17 CCR Section 95480-95503). The official URL:

https://govt.westlaw.com/calregs/Browse/Home/California/CaliforniaCodeofRegulations?guid=I06FA57F08B1811DF8121F57FB716B6E8&originationContext=documenttoc&transitionType=Default&contextData=(sc.Default).

In addition to the official URL, the unofficial version prepared by the staff can be found on the CARB website at: https://ww3.arb.ca.gov/fuels/lcfs/fro_oal_approved_clean_unofficial_010919.pdf.

2. CA-GREET 3.0 Model: California - Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model version 3.0. Developed by UChicago Argonne National Laboratory under Contract No. DE-AC02-06CH11357. (2018 release). URL: https://ww3.arb.ca.gov/fuels/lcfs/ca-greet/ca-greet.htm (Author: Wang, M., Argonne, IL).

3. CA - MRR: California Regulation for the Mandatory Reporting of Greenhouse Gas Emissions. The official version is published as CA CCR Title 17, Division 3, Chapter 1, Subchapter 10, Article 2 (17 CCR Section 95100-95163). The official URL: https://govt.westlaw.com/calregs/Index?transitionType=Default&contextData=%28sc.Default%29&bhcp=1.

The direct URL for Article 2: https://govt.westlaw.com/calregs/Browse/Home/California/CaliforniaCodeofRegulations?guid=I232C71302EBC11E194EACEFFB46E37D1&originationContext=documenttoc&transitionType=Default&contextData=(sc.Default).

In addition to the official URL, the unofficial version prepared by the staff can be found on the CARB website at:

https://ww3.arb.ca.gov/cc/reporting/ghg-rep/regulation/mrr-2018-unofficial-2019-4-3.pdf?_ga=2.225546394.1293446954.1573837908-1057749210.1546547258.

4. OPGEE v2.0: The Oil Production Greenhouse gas Emissions Estimator, (Prepared June 2017, released February 2018). Prepared by Hassan M. El-Houjeiri, Masnadi M.s., Vafi K., Duffy J., Brandt A., Department of Energy Resources Engineering, Stanford University. Prepared with funding from the California Air Resources Board. URL: https://eao.stanford.edu/research-areas/opgee.

5. CA- CCSP: California Carbon Capture and Sequestration Protocol (August 13, 2018). The CCSP is found on the CARB website, URL: https://ww3.arb.ca.gov/fuels/lcfs/ccs_protocol_010919.pdf.

In addition to the above sources, the Application Package refers to the following, as indicated specifically within the text of the application package:

6. CARB-1 Oxy Carbon Storage, LLC's application for Permanence Certification of Geologic Carbon Sequestration Projects CARB-1 Application for Permanence Certification (Application No. D001001). This application was submitted through the AFP system on November 4, 2019.

7. Johnson, M. C., Palou-Rivera, I., & Frank, E. D. (2013). Energy consumption during the manufacture of nutrients for algae cultivation. Algal Research, 2(4), 426–436. doi: 10.1016/j.algal.2013.08.003

8. McCollum, D. L, & Ogden, J. M. (2006). Techno-Economic Models for Carbon Dioxide Compression, Transport, and Storage & Correlations for Estimating Carbon Dioxide Density and Viscosity. UC Davis: Institute of Transportation Studies. Retrieved from https://escholarship.org/uc/item/1zg00532

9. Wang, Z., Benavides, P.T., Dunn, J., Cronauer, D.C., 2015 .Development of GREET Catalyst Module, ANL/ESD-14/12 Rev; Argonne National Laboratory.

7. Appendices

7.1. List of Certified Fuel Pathways

Certified fuel pathway list accessed at https://ww3.arb.ca.gov/fuels/lcfs/fuelpathways/pathwaytable.htm on 7/06/2020 and last updated 6/29/2020 by ARB staff.

Table A.1.1: List of Certified Fuel Pathways for White Energy Plainview (PWE)

App #	Class	Applicant & Pathway Description	Facility Location	Feedstock	Fuel Type	Previously Certified FPC	Previously Certified CI	Certified FPC	Certified CI	Certification Date	Public Comment & Others	Fuel Category	Company (ID)	Facility (ID)	Pathway Description
A016101	Tier 1	Fuel Producer: White Energy, Inc. (4745); Facility Name: Plainview BioEnergy, LLC (White Energy) (70039); Texas Corn, Dry Mill; Wet DGS, Corn oil and Syrup; Natural gas and Grid Electricity; Starch Ethanol produced in Plainview, Texas; Ethanol transported by rail to California	Texas	Corn (009)	Ethanol (ETH)	ETHC206	70.43	ETH009A01610100	64.69	10/8/2019	None	Ethanol	White Energy, Inc. (4745)	Plainview BioEnergy, LLC (White Energy) (70039)	Texas Corn, Dry Mill; Wet DGS, Corn oil and Syrup; Natural gas and Grid Electricity; Starch Ethanol produced in Plainview, Texas; Ethanol transported by rail to California
A016103	Tier 1	Fuel Producer: White Energy, Inc. (4745); Facility Name: Plainview BioEnergy, LLC (White Energy) (70039); Texas Sorghum, Dry Mill; Wet DGS, Corn oil and Syrup; Natural gas and Grid Electricity; Starch Ethanol produced in Plainview, Texas; Ethanol transported by rail to California	Texas	Grain Sorghum (010)	Ethanol (ETH)	ETHG202	77.05	ETH010A01610300	66.62	10/8/2019	None	Ethanol	White Energy, Inc. (4745)	Plainview BioEnergy, LLC (White Energy) (70039)	Texas Sorghum, Dry Mill; Wet DGS, Corn oil and Syrup; Natural gas and Grid Electricity; Starch Ethanol produced in Plainview, Texas; Ethanol transported by rail to California
A016104	Tier 1	Fuel Producer: White Energy, Inc. (4745); Facility Name: Plainview BioEnergy, LLC (White Energy) (70039); Texas Corn, Dry Mill; Dry DGS, Corn oil and Syrup; Natural gas and Grid Electricity; Starch Ethanol produced in Plainview, Texas; Ethanol transported by rail to California	Texas	Corn (009)	Ethanol (ETH)	ETHC205	78.02	ETH009A01610400	72.64	10/8/2019	None	Ethanol	White Energy, Inc. (4745)	Plainview BioEnergy, LLC (White Energy) (70039)	Texas Corn, Dry Mill; Dry DGS, Corn oil and Syrup; Natural gas and Grid Electricity; Starch Ethanol produced in Plainview, Texas; Ethanol transported by rail to California
A016105	Tier 1	Fuel Producer: White Energy, Inc. (4745); Facility Name: Plainview BioEnergy, LLC (White Energy) (70039); Texas Sorghum, Dry Mill; Dry DGS, Corn oil and Syrup; Natural gas and Grid Electricity; Starch Ethanol produced in Plainview, Texas; Ethanol transported by rail to California	Texas	Grain Sorghum (010)	Ethanol (ETH)	ETHG201	84.64	ETH010A01610500	74.57	10/8/2019	None	Ethanol	White Energy, Inc. (4745)	Plainview BioEnergy, LLC (White Energy) (70039)	Texas Sorghum, Dry Mill; Dry DGS, Corn oil and Syrup; Natural gas and Grid Electricity; Starch Ethanol produced in Plainview, Texas; Ethanol transported by rail to California

Table A.1.2: List of Certified Fuel Pathways for White Energy Hereford (HWE)

App #	Class	Applicant & Pathway Description	Facility Location	Feedstock	Fuel Type	Legacy FPC	Legacy CI	Current Certified FPC	Current Certified CI	Certification Date	Public Comment & Others	Fuel Category	Company (ID)	Facility (ID)	Pathway Description
A016301	Tier 1	Fuel Producer: White Energy, Inc. (4745); Facility Name: WE Hereford, LLC (70037); Midwest Corn, Dry Mill; Wet DGS, Corn oil and Syrup; Natural Gas and Grid electricity; Starch Ethanol produced in Hereford, Texas; Ethanol transported by rail to California	Texas	Corn (009)	Ethanol (ETH)	ETHC200	70.79	ETH009A01630100	64.74	12/16/2019	None	Ethanol	White Energy, Inc. (4745)	WE Hereford, LLC (70037)	Midwest Corn, Dry Mill; Wet DGS, Corn oil and Syrup; Natural Gas and Grid electricity; Starch Ethanol produced in Hereford, Texas; Ethanol transported by rail to California
A016302	Tier 1	Fuel Producer: White Energy, Inc. (4745); Facility Name: WE Hereford, LLC (70037); Kansas and Texas Sorghum, Dry Mill; Wet DGS, Corn Oil and Syrup; Natural Gas and Grid electricity; Starch Ethanol produced in Hereford, Texas; Ethanol transported by rail to California	Texas	Grain Sorghum (010)	Ethanol (ETH)	ETHG200	79.03	ETH010A01630200	66.63	12/16/2019	None	Ethanol	White Energy, Inc. (4745)	WE Hereford, LLC (70037)	Kansas and Texas Sorghum, Dry Mill; Wet DGS, Corn Oil and Syrup; Natural Gas and Grid electricity; Starch Ethanol produced in Hereford, Texas; Ethanol transported by rail to California

7.2. Carbon Intensity Calculation Assumptions

The key assumptions around estimating CO2 capture volumes from ethanol production are listed below for reference. These values and calculations are available for review under the CO2 Basis sheet and the Fuel_Specs sheet in the CARB-1 CI Calculator.

Table A.2.1: Ethanol and CO2 Basis Calculations

Ethanol and CO2 Basis Calculation			
Parameter	*Value*	*Unit*	*Comments and Assumptions*
CO2 Mass Captured, Daily	1,058	Metric Tonnes/day	Biogenic CO2 mass from Aspen HYSYS simulation
CO2 Volume Captured, Daily	19,990	MSCF/day	At standard conditions (oilfield convention) of 1 atm (14.696 psi) and 60F,
CO2 Volume Captured, Monthly	613,026	MSCF/month	92 days over 3 months in Q4 2021
CO2 Volume Vented, Monthly	32,265	MSCF/month	95% CO2 recovery using [redacted] capture plant design
CO2 Mass (Captured + Vented), Monthly	34145.3	Metric Tonnes/month	Total CO2 generated from ethanol production according to stoichiometry
Ethanol Mass, Monthly	35743.6	Metric Tonnes/month	Equal yield of ethanol and CO2 in fermentation reaction. Ethanol MW=46.07 g/g-mole, CO2 MW=44.01g/g-mole
Ethanol Volume, Monthly	11,962,370	Undenatured EtOH gal/month	Undenatured Ethanol density is 2,988 g/gal at 60F
Ethanol Volume, Monthly	12,269,097.12	Denatured EtOH gal/month	Denaturant volume is 2.5% of Denatured EtOH sales
Annual Ethanol Production	146,028,927.70	EtOH gallons	365 days of operation
Annual CO2 Capture	386,083.17	Metric Tonnes	365 days of operation

Table A.2.2: CO2 Volume to Mass Calculations

Parameter	Value	Unit	Comments/Assumptions
Moles of gas per SCF @ STP	1.202	g-mol/scf	At standard conditions (oilfield convention) of 1 atm (14.696 psi) and 60F, obtained from OPGEE
MSCF CO2 to Metric Tonnes	18.90	MCF/MT	
Molecular Weight of CO2	44.01	g/g-mole	

Table A.2.3: Ethanol Molecular Weight

Parameter	Value	Unit
Molecular weight of Ethanol	46.07	g/g-mole

7.3. List of Equations and Sample Calculations

7.3.1. Net GHG Emissions Reduction from Project

CCSP B.2.2(a) Equation 1

$GHG_{reduction} = CO2_{injected} - GHG_{project}$

$$CO2_{injected} = 1{,}839{,}079\ (MSCF\ CO2) \times \frac{1}{18.90} \frac{MT\ CO2}{MSCF\ CO2}$$

$$CO2_{injected} = 97{,}314.11\ MT\ CO2e\ per\ Quarter$$

$$GHG_{project} = 21{,}552.20\ MT\ CO2e\ per\ Quarter$$

$$GHG_{reduction} = 97{,}314.11\ MT\ CO2e - 21{,}552.20\ MT\ CO2e$$

$$GHG_{reduction} = 75{,}761.92\ MT\ CO2e\ per\ Quarter$$

Where:

$GHG_{reduction}$ = net GHG reductions (MT CO2e)

$CO2_{injected}$ = amount of injected CO2 (MT CO2e)

$GHG_{project}$ = CCS project GHG emissions (MT CO2e)

7.3.2. GHG Emissions from CCS Project

CCSP B.2.2(b) Equation 2

$GHG_{project} = GHG_{capture} + GHG_{transport} + GHG_{injection} + GHG_{dLUC}$

$GHG_{project} =$ [redacted] $MT\ CO2e +$ [redacted] $MT\ CO2e +$ [redacted] $MT\ CO2e + 0\ MT\ CO2e$

$$GHG_{project} = 21{,}552.20\ CO2e\ per\ Quarter$$

Where:

$GHG_{project}$ = CCS project emissions (MT CO2e)

$GHG_{capture}$ = GHG emissions associated with carbon capture, dehydration, and compression (MT CO2e)

$GHG_{transport}$ = GHG CO2 transport (MT CO2e)

$GHG_{injection}$ = GHG emissions from injection operations (MT CO2e)

GHG_{dLUC} = GHG emissions from direct land use change (MT CO2e)

The DLUC emissions are 16 MT CO2e and 22 MT CO2e per quarter for PWE and HWE respectfully.

$GHG_{project} =$ [redacted] $MT\ CO2e +$ [redacted] $MT\ CO2e +$ [redacted] $MT\ CO2e + 16(22)\ MT\ CO2e$

$$GHG_{project} = 21{,}568.20(21{,}574.20) CO2e\ per\ Quarter$$

7.3.3. GHG Emissions from Carbon Capture, Dehydration, and Compression

CCSP B.2.2(c) Equation 3

$GHG_{capture} = GHG_{combustion} + EmbodiedGHG_{electricity + steam} + EmbodiedGHG_{fuel} + EmbodiedGHG_{chemical}$

$GHGcapture =$ [redacted] $MT\ CO2e +$ [redacted] $(kWh) \times 795.05 \left(\frac{gCO2e}{kWh}\right) \times \frac{1\ MT\ CO2e}{10^6 gCO2e} + 0\ MT\ CO2e + 0\ MT\ CO2e$

$GHGcapture =$ [redacted] $MT\ CO2e\ per\ Quarter$

Where:

$GHG_{capture}$ = GHG emissions associated with carbon capture, dehydration, and compression (MT CO2e)

$GHG_{combustion}$ = GHG from fuel combustion in stationary equipment (MT CO2e)

$EmbodiedGHG_{electricity + steam}$ = Embodied (upstream) GHG emissions from purchased electricity and steam use (MT CO2e)

$EmbodiedGHG_{fuel}$ = Embodied (upstream) GHG emissions of fuel used in stationary equipment (MT CO2e)

$EmbodiedGHG_{chemical}$ = Embodied (upstream) GHG emissions from specialty chemicals used in carbon capture (MT CO2e)

7.3.4. GHG Emissions from Transport

CCSP B.2.2(d) Equation 4

$GHG_{transport} = GHG_{combustion} + \mathit{Embodied}GHG_{electricity} + \mathit{Embodied}GHG_{fuel}$

$$GHGtransport = \text{[redacted]}\ MT\ CO2e\ \text{[redacted]}\ (kWh) \times 795.05\ \left(\frac{gCO2e}{kWh}\right) \times \frac{1\ MT\ CO2e}{10^6 gCO2e} + 0\ MT\ CO2e$$

$$GHGtransport = \text{[redacted]}\ MT\ CO2e\ per\ Quarter$$

Where:

$GHG_{transport}$ = GHG emissions associated with CO2 transport (MT CO2e)

$GHG_{combustion}$ = GHG from fuel combustion in stationary equipment (MT CO2e)

$\mathit{Embodied}GHG_{electricity}$ = Embodied (upstream) GHG emissions from electricity use (MT CO2e)

$\mathit{Embodied}GHG_{fuel}$ = Embodied (upstream) GHG emissions of fuel used in CO2 transport (MT CO2e)

7.3.5. GHG Emissions from CO2 Injection Operations

CCSP B.2.2(e) Equation 5

$GHG_{injection} = GHG_{combustion} + \mathit{Embodied}GHG_{electricity+steam} + \mathit{Embodied}GHG_{fuel} + CO2_{vent} + CO2_{fugitive} + CO2_{entrained} + CO2_{leakage} + CO2_{transfer}$

$$GHG_{combustion} = \text{[redacted]}\ (mmBTU) \times 73{,}424\ \left(\frac{gCO2e}{mmBTU}\right) \times \frac{1\ MT\ CO2e}{10^6 gCO2e} \times \left(\frac{\text{[redacted]}\%\ CO2\ in\ Recycle\ Gas}{Total\ Recycle\ Gas}\right) \times \left(\frac{\text{[redacted]}\%\ Biogenic\ CO2\ from\ Single\ EtOH\ Plant}{Total\ CO2\ Sequesterd\ in\ CARB1}\right)$$

$$GHG_{combustion} = \text{[redacted]}\ MT\ CO2e\ per\ Quarter$$

$$EmbodiedGHG_{electricty+steam} = \text{[redacted]}\ (kWh) \times 795.05\ \left(\frac{gCO2e}{kWh}\right) \times \frac{1\ MT\ CO2e}{10^6 gCO2e} \times \left(\frac{\text{[redacted]}\%\ CO2\ in\ Recycle\ Gas}{Total\ Recycle\ Gas}\right) \times \left(\frac{\text{[redacted]}\%\ Biogenic\ CO2\ from\ Single\ EtOH\ Plant}{CO2\ Sequesterd\ in\ CARB1}\right)$$

$$EmbodiedGHG_{electricty+steam} = \text{[redacted]}\ MT\ CO2e\ per\ Quarter$$

$$CO2_{vent} = \text{[redacted]}\ MT\ CO2e \times \left(\frac{\text{[redacted]}\%\ Biogenic\ CO2\ from\ Single\ EtOH\ Plant}{Total\ CO2\ Sequesterd\ in\ CARB1}\right)$$

$$CO2_{vent} = 100.33\ MT\ CO2e\ per\ Quarter$$

$$CO2_{fugitive} = \text{[redacted]}\ MT\ CO2e \times \left(\frac{\text{[redacted]}\%\ Biogenic\ CO2\ from\ Single\ EtOH\ Plant}{Total\ CO2\ Sequesterd\ in\ CARB1}\right)$$

$$CO2_{fugitive} = 17.92\ MT\ CO2e\ per\ Quarter$$

$$CO2_{entrained} = \text{[redacted]}\ MT\ CO2e \times \left(\frac{\text{[redacted]}\%\ Biogenic\ CO2\ from\ Single\ EtOH\ Plant}{Total\ CO2\ Sequesterd\ in\ CARB1}\right)$$

$$CO2_{entrained} = 14.47\ MT\ CO2e\ per\ Quarter$$

$CO2_{leakage} = 0\ MT\ CO2e\ per\ Quarter$

$CO2_{transfer} = 0\ MT\ CO2e\ per\ Quarter$

$GHG_{injection} =$ [redacted] $MT\ CO2e +$ [redacted] $MT\ CO2e + 100.33\ MT\ CO2e + 17.92\ MT\ CO2e + 14.47\ MT\ CO2e$

$GHG_{injection} =$ [redacted] $MT\ CO2e\ per\ Quarter$

Where:

$GHG_{injection}$ = GHG emissions associated with CO2 injection operations in CO2EOR (MT CO2e)

$GHG_{combustion}$ = GHG from fuel combustion in stationary equipment (MT CO2e)

Embodied$GHG_{electricity+steam}$ = Embodied (upstream) GHG emissions from electricity and steam use (MT CO2e)

EmbodiedGHG_{fuel} = Embodied (upstream) GHG emissions of fuel used in CO2 injection and recycling (MT CO2e)

$CO2_{vent}$ = CO2 emissions from venting (MT CO2e)

$CO2_{fugitive}$ = Fugitive CO2 emissions (MT CO2e)

$CO2_{entrained}$ = Entrained CO2 produced in water, other gas, and crude oil sent off lease (MT CO2e)

$CO2_{leakage}$ =Atmospheric CO2 leakage from the storage complex (MT CO2e)

$CO2_{transfer}$ = Intentional transfer of stored CO2 outside of the CCS project boundary (MT CO2e)

7.3.6. CO2 Allocation Factor

The CI reduction for Ethanol + CCS fuel pathway will be updated according to the rate at which biogenic CO2 is sequestered inside CARB 1. A mass balance dependent emissions allocation factor, CO2 Allocation factor or CAF, has been created to distribute the various categories of GHG emissions defined under the CCSP.

CO2 Allocation Factor Equation

CAF = (Biogenic $CO2_{injected}$) / (Total $CO2_{Sequestered}$)

Where:

Biogenic $CO2_{injected}$ = Biogenic CO2 volumes sequestered in CARB-1, in a given year

Total $CO2_{Sequestered}$ in CARB1 = Biogenic $CO2_{injected}$ + Other $CO2_{injected}$ + Other Biogenic $CO2_{injected}$

Other $CO2_{injected}$ = Other CO2 volumes sequestered in CARB-1 for CO2-EOR operations, in a given year

Other Biogenic $CO2_{injected}$ = Biogenic CO2 volumes sequestered from other CCS projects in CARB-1, in a given year

Example Calculation:

$CAF, 2021 = \frac{20\ MMSCFD}{[redacted]\ MMSCFD}$

$CAF, 2021 =$ [redacted] $\%\ \frac{Biogenic\ CO2\ Single\ Ethanol\ Plant}{Total\ CO2\ Sequestered\ in\ CARB1}$

Table A.3.1: Actual and Forecasted CO2 Injection Volumes and CO2 Allocation Factors

Year	Seqestered CO2 Injection Rate	Other CO2 Injection Rate	One EtOH Plant Biogenic CO2 Injection Rate	One EtOH Plant CAF	Two EtOH Plant Biogenic CO2 Injection Rate	Two EtOH Plant Biogenic CO2 Cumulative Volume Sequestered	Two EtOH Plant Biogenic CO2 Cumulative Mass Sequestered
	(Mscf/day)	(Mscf/day)	(Mscf/day)	%	(Mscf/day)	(Bcf)	(Metric Tons)
2013	[redacted]	[redacted]	0	0.00%	0	0	0
2014	[redacted]	[redacted]	0	0.00%	0	0	0
2015	[redacted]	[redacted]	0	0.00%	0	0	0
2016	[redacted]	[redacted]	0	0.00%	0	0	0
2017	[redacted]	[redacted]	0	0.00%	0	0	0
2018	[redacted]	[redacted]	0	0.00%	0	0	0
2019	[redacted]	[redacted]	0	0.00%	0	0	0
2020	[redacted]	[redacted]	0	0.00%	0	0	0
2021	[redacted]	[redacted]	20,000	[redacted]%	40,000	[redacted]	[redacted]

Sequestered CO2 Injection rate volumes in Table A.3.1 do not include recycle volumes.

7.4. CCS Project Description

Figure A.4.1 shows the approximate location of the planned and existing facilities and pipelines that are part of this CCS Project.

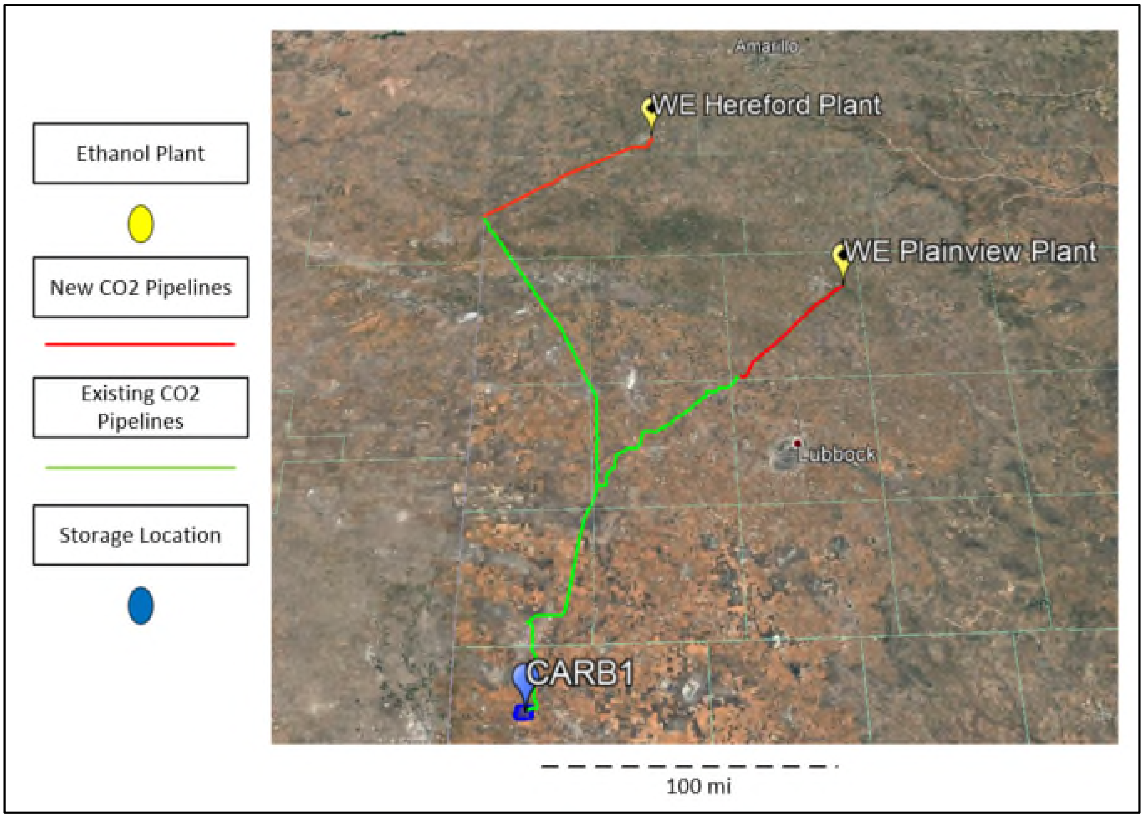

Figure A.4.1 – Satellite View of Permian CO2 Pipeline Network

The project will include:

a) CO_2 Capture: Capture equipment will be installed at existing ethanol plants in Hereford (HWE) and Plainview (PWE) Texas, indicated by the yellow markers in the upper right of Figure A.4.1. The ethanol plants are owned and operated by White Energy (WE). The CO_2 capture facilities are currently being designed for construction. Technical specifications have been provided to vendors and bids are currently under review.

b) CO_2 Transportation: Delivery of captured CO_2 will be through a pipeline network consisting of new dedicated CO_2 pipelines connecting to the existing Permian CO_2 Pipeline Network. As per the PFD drawing PER-TBD-PRO-00001-005, the new CO_2 pipelines are shown in red and the existing CO_2 pipelines are shown in green in Figure A.4.1. Dedicated and calibrated flowmeters will be installed to meter and account for the biogenic CO_2 captured at each WE plant and delivered to the Permian CO_2 Pipeline Network. Existing dedicated and calibrated flowmeters will properly meter and account for the biogenic CO_2 from the network and delivered to CARB-1.

c) CO_2 Sequestration: Sequestration will occur at CARB-1 located in Gaines County, Texas, indicated by the blue marker in the bottom left of Figure A.4.1.

Figure A.4.2 presents a block flow diagram of the Design-based pathway; it will be used as a reference point for the detailed descriptions to follow.

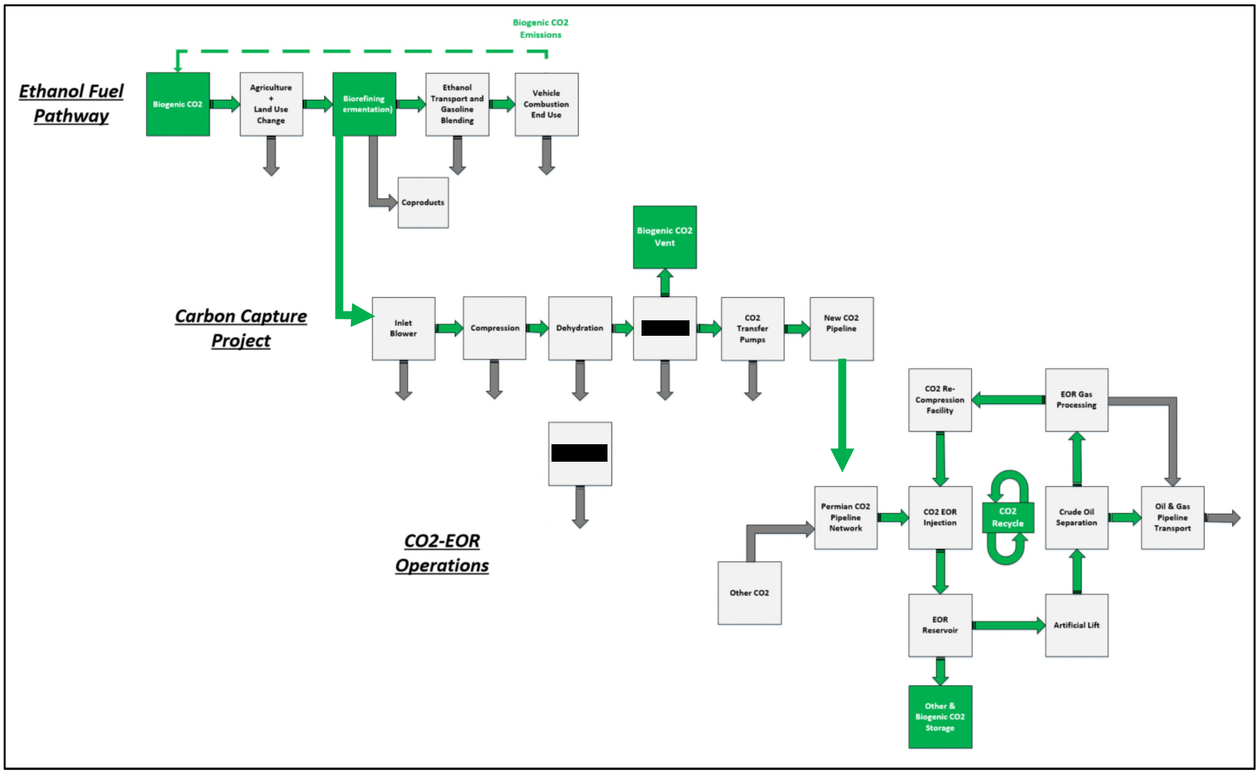

Figure A.4.2 – Block flow diagram of Design-based Pathway

The Design-based pathway incorporates three separate processes; 1) Ethanol Production, 2) Carbon Capture, and 3) Crude Oil and Gas Production from CO2-EOR. The green arrows and boxes represent captured biogenic CO2 from ethanol production and the gray arrows represent emissions or other sources of CO2 for CO2-EOR operations.

7.4.1. Detailed Description of Capture System

The capture system will include the technology to capture and process CO2 at the two ethanol plants and move that CO2 into a pipeline transportation system for ultimate sequestration in an ongoing CO2-EOR project. The capture facilities at both HWE and PWE will utilize the same technology and have a maximum throughput capacity of 1,100 metric tonnes per day.

The stages of capture relevant for the CI calculation are described below:

(a) Inlet Blower

Biogenic CO2 from ethanol production exits the fermentation reactor through a process vent and enters the inlet blower. At this stage, the CO2 is a wet gas at approximately atmospheric pressure that needs to be compressed, dehydrated, and purged of inert gasses before it is suitable for supercritical phase transport. A custody transfer meter and analyzers will be installed to measure the CO2 that leaves the ethanol plant and enters the CO2 capture facility.

The blowers will boost the wet CO_2 from atmospheric pressure to ~[redacted] psia. Inlet blower after coolers will then cool the CO_2 stream to [redacted]°F. Any condensation from inlet blower operations will be collected and sent back to the ethanol plant for recycle via a water condensate pump. The inlet blowers estimated brake horsepower (BHP) is [redacted] HP (three (3) multistage centrifugal blowers operating at 33% load, [redacted] HP each).

The [redacted] is located after the inlet blower after coolers and the discharge gas scrubbers. The [redacted] will [redacted] the CO_2 stream to [redacted]°F before the first stage of compression.

(b) Compression

The compressors estimated BHP is [redacted] HP (three (3) two-stage lube oil flooded screw compressors operating at 33% load, [redacted] HP each). The CO_2 stream will pass through an air cooler and then the [redacted] to approximately [redacted]° F. A discharge scrubber will separate water condensation and combine it with the water collected at the blower skids to be recycled. After this initial cycle of compression and [redacted], the CO_2 stream will be heated to [redacted]° F by a preheater before dehydration.

(c) Dehydration

In the dehydration stage, the CO_2 stream will pass over one of [redacted] with a [redacted]. While [redacted] is in use, the other [redacted] will be undergoing [redacted]. A moisture analyzer will be located downstream of the [redacted] to monitor dehydration performance.

(d) [redacted]

The dehydrated CO_2 stream will be condensed to a liquid using a series of [redacted] and the [redacted]. Then the liquefied CO_2 will flow to the CO_2 [redacted] where it will be purified to meet a pipeline specification. The equipment in the [redacted] will include [redacted], [redacted] equipment, [redacted], and [redacted]. The non-condensable gasses will be vented.

(e) [redacted]

The Capture Process uses a [redacted] system in both the compression and [redacted] stages. The [redacted] remains separate from the CO_2. [redacted] will be [redacted] through the [redacted] units and then flow back through the main compressor for [redacted].

(f) Chemicals

The Capture Process does not use any specialty chemicals as specified by the CCSP for CO_2 capture. The process uses [redacted] for dehydration, [redacted], and lube oil for compressors and associated rotating equipment. Estimated usage is available in Appendix 7.5.2.

7.4.2. Detailed Description of Transport System

The transportation system includes CO2 transfer pumps at each capture facility to transport CO2 to CARB-1 for sequestration.

(a) CO2 Transfer Pumps

Purified CO2 will leave the [redacted] of the [redacted] in dense or supercritical phase and flow to a pair of electrically driven centrifugal pumps. These CO2 transfer pumps will send the supercritical phase CO2 through a [redacted], which raises the CO2 to the average pipeline temperature of [redacted]°F, and into the new CO2 pipeline. A custody transfer meter and analyzers will be located at the outlet of the CO2 capture facility to measure the amount of CO2 flowing into the pipeline.

(b) New CO2 Pipelines

Two (2) new dedicated pipelines will be designed and installed to transport CO2 from HWE and PWE to the Permian CO2 Pipeline Network. Both pipelines will be DOT regulated and will operate at approximately [redacted] psig.

(b.i) HWE New CO2 Pipeline

The new CO2 pipeline from HWE to OXY Bravo Pipeline segment of the Permian CO2 Pipeline Network will be 8" in diameter and approximately 48 miles in length. The total elevation change from HWE to OXY Bravo Pipeline is 926 feet as shown in Figure A.4.3.

Figure A.4.3 – Satellite Image of Pipeline Routing Connecting HWE to OXY Bravo Pipeline (b.ii) PWE New CO2 Pipeline

The new CO2 pipeline from PWE to OXY Anton Pipeline segment of the Permian CO2 Pipeline Network will be 6” in diameter and approximately 35 miles in length. The total elevation change from PWE to OXY Anton Pipeline is 676 feet as shown in Figure A.4.4.

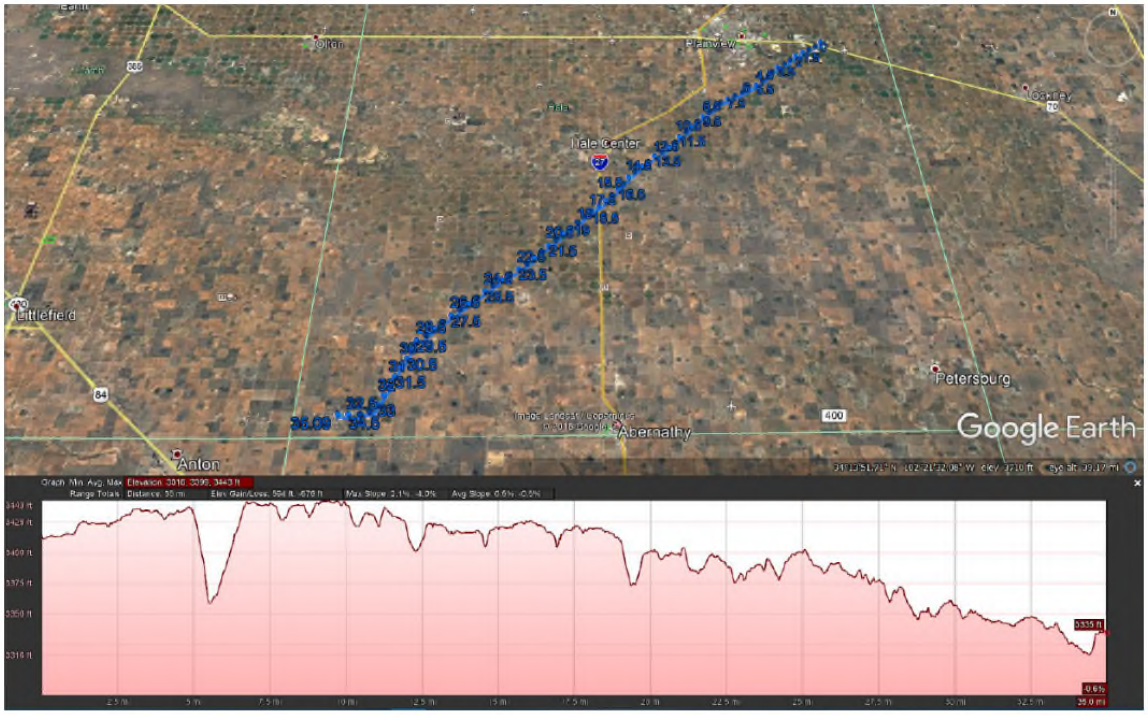

Figure A.4.4 – Satellite Image of Pipeline Routing Connecting PWE to OXY Anton Pipeline

(c) Transport Through the Permian CO2 Pipeline Network

The CCS Protocol requires applicants to include the energy and associated emissions for transporting CO2 from the point of capture to the point of sequestration in the overall CCS project LCA. Figure A.4.5 shows the pipeline network used in the calculation.

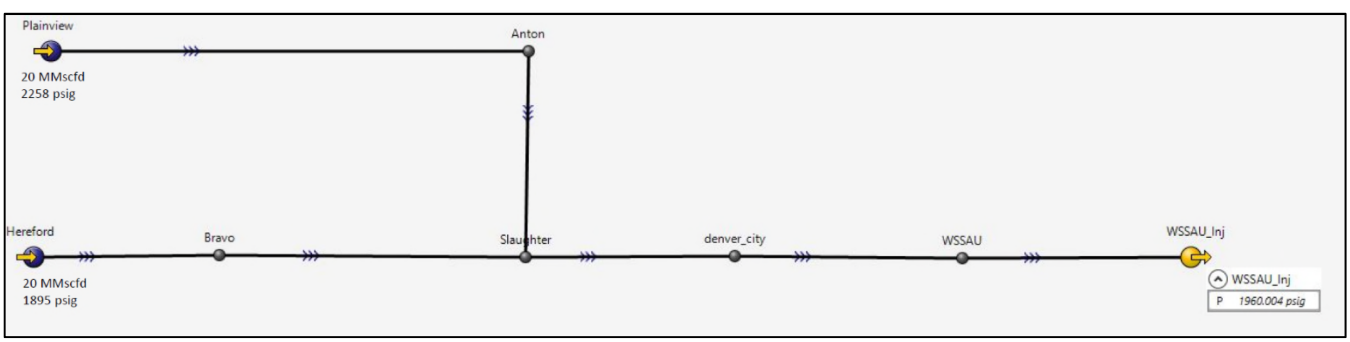

Figure A.4.5 – PIPESIM Network Model Schematic for Permian CO2 Pipeline Network

This application uses a mechanical energy balance to calculate the energy required to transport CO2 from the two ethanol capture facilities to the CO2-EOR sequestration site. The inputs for the mechanical energy balance, commonly known as a hydraulic analysis, include pipeline length, elevation profile data, pipeline size and wall thickness data, anticipated biogenic CO2 volumes, and pipeline operating pressure. PIPESIM was the hydraulic simulator used to calculate the energy required for CO2 transport. Table A.4.1 shows the results from the hydraulic analysis.

Table A.4.1 – PIPESIM Network Model for Permian CO2 Pipeline Network Results

	Biogenic CO2 Flowrate	Network Distance	HP Required	Pump Discharge
HWE	20 MMSCFD	139 mi	[redacted] HP	[redacted] psig
PWE	20 MMSCFD	183 mi	[redacted] HP	[redacted] psig

7.4.3. Detailed Description of Injection System

WSSAU utilizes a closed loop CO2-EOR process where the produced gas is reinjected into the reservoir for additional enhanced oil recovery and only the crude oil is sold to the market.

(a) CO2-EOR Injection

The CO2 used for enhanced oil recovery is obtained through the Central Basin Pipeline (CBPL). A custody transfer meter is located near the CBPL connection point. A pipeline routes CO2 to a manifold where it is mixed with recycled produced gas consisting of primarily recompressed CO2 coming from the West Seminole Reinjection Compressor Facility (RCF). The CO2 is then routed to the injection trunk lines and manifolds for injection into the EOR reservoir.

(b) EOR Reservoir and Artificial Lift

Injectant primarily consisting of CO2 and water mix with hydrocarbons in the reservoir and move towards producer wells. Pumps create artificial lift that is used to move the produced fluid to a production separator located at the Satellite Batteries (SAT). Gas from the production separator is sent to the RCF. The oil and water phase from the production separator is sent to the inlet separator located at the Central Tank Battery (CTB).

(c) Crude Oil Separation and EOR Gas Processing

The CTB is the primary oil/water separation system for the CO2 project. Gas from the CTB inlet separator is sent to a low pressure (LP) compressor, which compresses the gas to the RCF facility. The liquid from the inlet separator flows to a tank where it is de-gassed and the oil and water are separated.

Produced oil flows to the oil tanks and then to the Lease Automated Custody Transfer (LACT) where it is metered and sold into the oil pipeline. The produced water flows to the water tank and subsequently to the water injection pumps for re-injection into injection wells. Vapors from the separation process are r ecovered and sent to the inlet separator.

The bottom right of Figure A.4.2 is a block flow diagram for a typical CO2-EOR operation and shows the potential for selling hydrocarbons from EOR gas processing. However, as the WSSAU uses a closed loop CO2-EOR process, there are no sales from EOR gas processing and produced gas is reinjected into the re servoir. A more detailed depiction of the WSSAU surface facility is shown by drawing PER-TBD-PRO-0000 1-008.

(d) CO_2 Re-Compression Facility

Gas entering the RCF consists of produced gas from the SAT and the CTB LP compressor. Prior to compression, the inlet gas is dehydrated by a triethylene glycol (TEG) dehydration system. The dehydrated gas is compressed using two parallel trains each consisting of three compression stages. The resulting supercritical phase fluid flows to the CO_2 injection system for reinjection.

7.5. CCSP Appendices

7.5.1. Appendix B. CO2 Venting and Fugitive Emissions from CO2-EOR Operations

Table A.5.1: Embedded GHG Emissions CO2 Venting and Fugitive Emissions

Appendix B. Venting and Fugitive Emissions from CO2-EOR OPS								
MRR VFF Category for CO2-EOR	**MRR Section**	**Applicable to WSSAU**	**Estimated CO2 Emissions**					
			SAT	**CTB**	**RCF**	**CO2 Injection**	**Annual Total (MT CO2/Year)**	**Daily Total (MT CO2/Day)**
Metered NG Pneumatic Device and Pumps	95153(a)	No						
Non-Metered NG Pneumatic Device and Pumps	95153(a)	No						
Acid Gas Removal Vents	95153(c)	No						
Dehydrator Vents	95153(d)	No						
Gas Well Completions and Workovers	95153(f)	No						
Equipment and Pipeline Blowdowns	95153(g)	Yes	Included in Associated Gas Volumes					
Dump Valves	95153(h,i)	No						
Well Testing Vented Emissions	95153(j)	No						
Associated Gas	95153(k)	Yes	0	172.73	952.4	0	1125.13	3.08
Centrifugal Compressor Vented Emissions	95153(m)	Yes	Included in Associated Gas Volumes					
Reciprocating Compressor Vented Emissions	95153(n)	Yes	Included in Associated Gas Volumes					
EOR Injection Pump Blowdown Emissions	95153(u)	No						
Fugitives	95153(p)	Yes	58.28	17.05	49.19	76.91	201.43	0.55
			Totals				1326.56	3.63
Notes:								
Associated Gas Volumes include Equipment and Pipeline Blowdown Venting Emissions. Most recent gas analyses were used to estimate Associated Gas and Fugitive Emissions. These will be updated for every reporting year per MRR/CCSP requirements.								

7.5.2. Estimated Embedded GHG for Process Chemicals

Embedded emissions for chemical production have been estimated using Emissions Factors from GREET 2019 from ANL.

Table A.5.2: Embedded GHG Emissions for CO2 Capture Chemicals

Embedded Emissions for Initial Chemical Inventory of Capture System						Capture System Annual Make Up		
Chemical	Initial Fill Material (lb)	Initial Fill Material (kg)	Emissions Factor (kg CO2e/kg)	Capture System Initial Fill GHG (MT CO2e)	Capture System Initial Fill GHG (MT CO2e/30 years)	(lb)	(kg)	(MT CO2e/year)
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]						[redacted]	[redacted]	[redacted]
Compressor Lube Oil	8,837	4,008	3.31	13.27	0.44	3,553	1,612	5.34
Totals	36,837	16,709		52.56	1.75	4,625	2,098	7.19

[redacted]:

[redacted] are [redacted], very similar to other [redacted]. Typical [redacted] are composed of [redacted], [redacted], and [redacted] was selected from the GREET products list to represent the embedded emissions from the [redacted]. The GHG-100 value ([redacted] kg CO2e/kg [redacted] from the Well to Use Emissions Table was selected to estimate embedded chemical emissions. Annual make up assumes [redacted]% [redacted] replacement every [redacted] years for [redacted] years.

Reference: *Wang, Z., Benavides, P.T., Dunn, J., Cronauer, D.C., 2015 .Development of GREET Catalyst Module, ANL/ESD-14/12 Rev; Argonne National Laboratory.*

[redacted]:

[redacted] was selected from the GREET products list to represent the embedded emissions from the initial [redacted] fill. The GHG-100 value ([redacted] kg CO2e/kg [redacted]) from the Well to Use Emissions Table was selected to estimate the embedded chemical emissions. Annual make up estimate is [redacted]% of the [redacted] every [redacted] years.

Reference: Johnson, M. C., Palou-Rivera, I., & Frank, E. D. (2013). *Energy consumption during the manufacture of nutrients for algae cultivation. Algal Research, 2(4), 426–436. doi: 10.1016/j.algal.2013.08.003*

Compressor Lube Oil:

Engine Oil Production was selected from the GREET products list to represent the embedded emissions from the initial compressor lubrication oil fill. The GHG-100 value (3.31 kg CO2e/kg) from the Well to Use Emissions Table was selected to estimate the embedded chemical emissions. Annual make up quantity is based on similar equipment at 400 gallons of 8.8837 lb/gal density lube oil.

Reference: *GREET 2019 Engine Oil Production Wells to Use Emissions Factor.*

7.5.3. Estimated CO2 Entrained Volumes in Crude Oil Sales

Table A.5.3: Estimated CO2 Entrained Volumes in Crude Oil Sales for WSSAU

Crude Oil Composition		
Comp		Mole Frac
Nitrogen	N_2	[redacted]
Carbon Dioxide	CO_2	0.29
Hydrogen Sulfide	H_2S	[redacted]
Methane	CH_4	[redacted]
Ethane	C_2H_6	[redacted]
Propane	C_3H_8	[redacted]
Isobutane	C_4H_{10}	[redacted]
n-Butane	C_4H_{10}	[redacted]
Isopentane	C_5H_{12}	[redacted]
n-Pentane	C_5H_{12}	[redacted]
Hexanes +	C_6H_{14} +	[redacted]
	Total	100.00

Gravity	
Relative Density, 60/60	0.8324
Degrees API, 60F	38.5
Molecular Weight	
Molar Mass	195.756

CO2 Entrainment Estimate Calculation - Single Barrel Basis				
1) Crude Oil Vol to Mass	2.92E+02	lb Oil/day	6) MT CO2/ BBL	8.62E-05
2) Crude Oil Mass to Moles	1.49E+00	lb-mole Oil/day		
3) Total Moles to CO2 Moles	4.32E-03	lb-mole CO2/day		
4) CO2 Moles to Mass	1.90E-01	lb CO2/day		
5) Convert lb to MT	8.62E-05	MT CO2/day		